Structures 15 (2018) 1–12

Contents lists available at ScienceDirect

Structures

journal homepage: www.elsevier.com/locate/structures

Experimental and Numerical Studies on Efficiency of Hybrid Overlay and Near Surface Mounted FRP Strengthening of Pre-cracked Hollow Core Slabs

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ARTICLE INFO

Keywords:
Hollow core slab
CFRP
NSM strengthening
Hybrid strengthening
Pre-cracked

ABSTRACT

Prestressed precast hollow core slabs (PPHCS) are commonly used as floor elements in the precast buildings. These slabs could crack due to various reasons and can affect the overall integrity of the structure. Also, tension stiffening of concrete in PPHCS is not as effective due to the absence of additional reinforcement other than prestressing strands and the transition between a flexurally 'uncracked' and flexurally 'cracked' section is rapid. Therefore, strengthening of such cracked slabs is essential for ensuring its adequate performance. Effect of FRP strengthening of hollow core slabs is relatively well established. However, the effect of hybrid strengthening on the behavior of pre-cracked hollow core slabs is not fully understood yet. The performance of pre-cracked hollow core slabs strengthened with near surface mounting (NSM) of carbon fiber reinforced polymer (CFRP) laminates, and hybrid strengthening is investigated. Hybrid strengthening includes a combination of concrete bonded overlay in the compression zone and NSM CFRP laminates in the tension zone. A total of eight full-scale hollow core slabs are tested at two different shear span (a) to the depth (d) ratios of 3.75 and 7.50. Before strengthening of the hollow core slabs, the slabs were pre-cracked by applying the load equal to 65% of its ultimate capacity. Strengthening by NSM technique increased the ultimate capacity of the slabs by 50% whereas hybrid strengthening increased the strength by 130% when compared to pre-cracked control specimens. Finite element (FE) models were developed and calibrated to predict the behavior of tested hollow core slabs. Peak load predictions obtained from the finite element analysis had good correlation with the test results.

1. Introduction

Hollow core slabs (HCS) are one of the widely used precast elements in the building construction industry. These elements do not have any additional flexural and shear reinforcement other than the prestressing strands. These elements could be quickly cast with automated machines through extrusion and slip forming process. Prestressed precast hollow core slabs (PPHCS) members are most commonly used as flooring or roof elements. These slab elements could have structural cracks due to overloading, or due to impact loads during transportation and erection. These structural deficiencies and reduction in capacity can be quickly rectified by strengthening the cracked slabs with fiber reinforced polymers (FRP). FRP strengthening has many advantageous over conventional techniques such as bonding with steel plates and concrete enlargement due to the ease in the installation process and because of their superior mechanical properties.

A significant amount of research has previously focused on flexural strengthening of undamaged reinforced concrete (RC) members and prestressed concrete members (PSC) using FRP composites [1–9]. However, only limited studies are available on the strengthening of pre-damaged or pre-cracked RC and PSC members. Dong et al. [10] carried out experimental studies on pre-cracked RC beams strengthened with carbon FRP sheets (CFRP). They studied the effect of different amounts of CFRP longitudinal reinforcement ratio. The authors found that flexural capacity of strengthened beams enhanced by 41% to 121% when compared with the control beams. David et al. [11] studied the effect of pre-cracking on the efficiency of externally bonded CFRP sheet strengthening. They varied the percentage of CFRP reinforcement and found that externally bonded CFRP reinforcement increased the strength and stiffness of pre-cracked beams. They also found that the displacement performance of CFRP repaired pre-cracked beams was better than the un-cracked CFRP strengthened beams. Morsy et al. [12] investigated the effect of flexural strength of pre-damaged RC beams strengthened with CFRP rebars by NSM technique. The authors performed full-scale testing of beams preloaded to 50%, 70% and 100% of its ultimate load and concluded that the embedded CFRP rebars could

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https://doi.org/10.1016/j.istruc.2018.05.003
Received 13 January 2018; Received in revised form 1 April 2018; Accepted 6 May 2018
Available online 08 May 2018

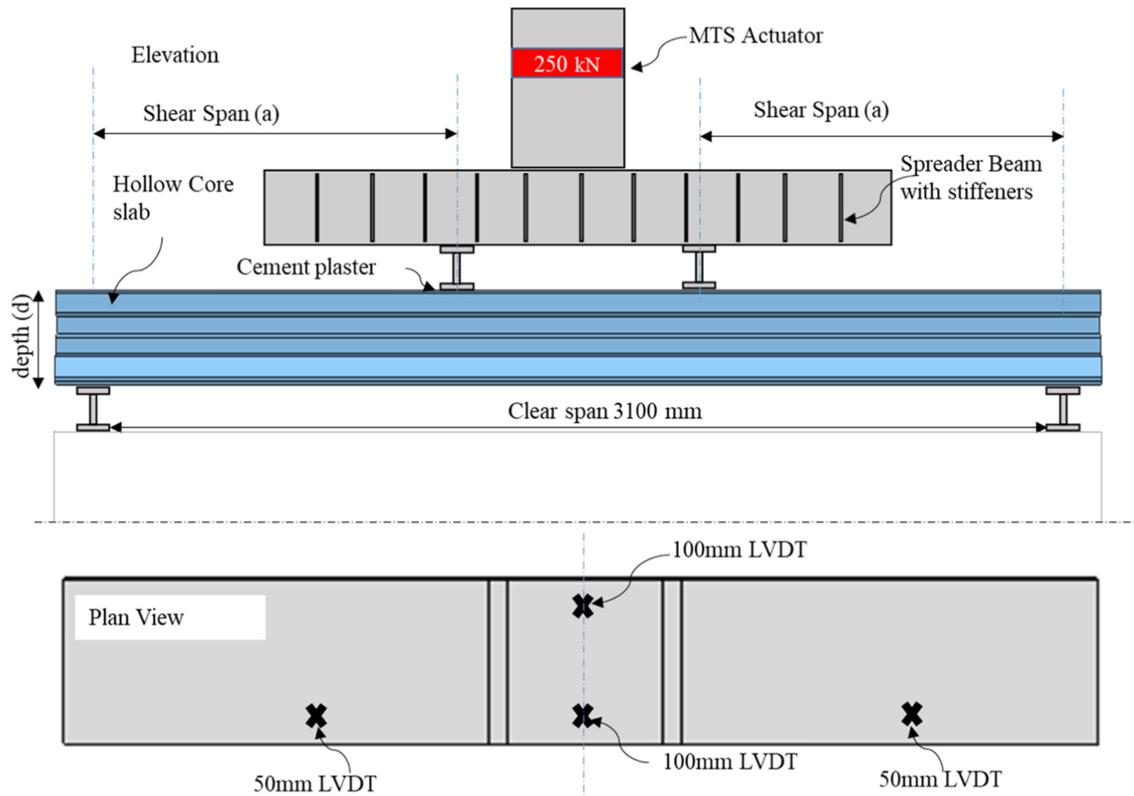

Fig. 1. Schematic of test setup.

enhance the flexural capacity by 33%. They noted that preloading had only a minor effect in the enhancement capacity of RC beams. Dirar et al. [13] carried out an experimental study on the strengthening of pre-cracked RC T-beams in shear using prestressed CFRP laminates. The authors concluded that strengthening could enhance the capacity by 46% when compared to equivalent un-strengthened beams. Duarte et al. [14] performed experimental and numerical work on pre-cracked RC beams strengthened with CFRP laminates. Experimental results showed that repairing the cracks using epoxy injection before strengthening them with CFRP laminates provided a considerable increase of stiffness, but only led to the slight increase in ultimate strength.

Dias and Barros [15] performed experiments on the shear strengthening of pre-cracked RC beams using CFRP laminates. The authors concluded that the principal difference in the behavior of strengthened beams with and without pre-cracks could be resumed but with loss of initial stiffness in the pre-cracked specimens. However, the pre-cracking did not affect the efficacy of the NSM shear strengthening on the load carrying capacity and ultimate deflection. Shihada and Oida [16] investigated the flexural capacity of pre-cracked RC beams strengthened with several cementitious materials. In this study, the authors used four cementitious repair materials viz., Ultra High-Performance Concrete (UHPC), Ultra High-Performance Fiber Reinforced Concrete (UHPFRC), Normal Strength Concrete (NSC) and Cement-based Repair Material (CRM) for restoring the flexural capacity of the beam. The authors concluded that the beams repaired using UHPFRC and CRM showed lesser flexural cracks compared to NSC. Moreover, they did not recommend the use of NSC for repairing the damaged beams. It is worth mentioning that only limited information is available on the strengthening of undamaged hollow core slabs with FRP composites [17–23]. Moreover, no research information is available on the repair efficiency of pre-cracked hollow core slabs using hybrid bonded overlay and FRP strengthening or only with FRP composites. The present study tries to fill this knowledge gap by testing eight full-scale slabs with and without pre-cracking and strengthened with different techniques under flexure and shear dominant loads.

2. Research motivation

Hollow core slabs are designed as un-cracked members at full-service load level. A significant issue in the performance of the hollow core section is that flexural cracks propagate more rapidly through the web than it would otherwise in a section with additional flexural reinforcement. Besides, tension stiffening of concrete is not as effective due to the absence of any additional reinforcement other than prestressing strands. Due to this, the transition between a flexurally 'uncracked' and flexurally 'cracked' section is rapid in hollow core slabs. These factors affect the crack propagation and reduce the post-cracking stiffness and ductility significantly. As mentioned earlier, these precast slabs are prone to cracks during transportation or erection and due to unplanned excessive loading. Though this cracking might not decrease the ultimate capacity of the slab, it would significantly affect the serviceability performance of the slabs leading to higher deflections. Instead of discarding the cracked sections, simple strengthening of the slabs could improve the performance of the slabs, thus saving costs. Therefore, the objective of this study to understand the behavior of pre-cracked hollow core slabs strengthened with different techniques. One high and low a/d ratios of 7.5 and 3.75 were selected to understand the effect of flexure to shear ratio on the efficiency of strengthening. Strengthening techniques considered are i) near-surface mounting of CFRP laminates (NSM CFRP) and ii) hybrid strengthening, which includes the combination of bonded overlay and NSM CFRP laminates. The hybrid strengthening scheme is selected to replicate the field condition. In field application, an overlay screed of 50 mm thick is usually provided on the hollow core slabs as a topping which serves the purpose of the base for floor finishing. As the PPHCS are simply supported, the provision of bonded overlay at the top increases the compressive zone in the section. Bonded overlay creates more effective